OPTIMAL CONTROL OF TIP-TILT MODES

REAL SKY ADAPTIVE OPTICS DEMONSTRATION

Niek Doelman – TNO Opto-Mechatronics, NL.
E: niek.doelman@tno.nl; T: +31 8886 68006
Remco den Breeje – TNO Opto-Mechatronics, NL.
Rufus Fraanje – Delft University of Technology, NL.

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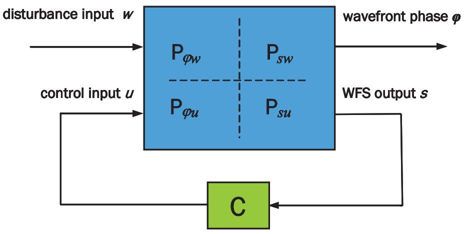
THE PERFORMANCE OF OPTIMAL CONTROL FOR ADAPTIVE OPTICS HAS BEEN DEMONSTRATED IN A REAL SKY EXPERIMENT ON A SOLAR TELESCOPE. THE RESULTS CORRESPOND WELL WITH SIMULATIONS.

INTRODUCTION

In recent years various researchers have proposed improved control design methods for AO systems, aiming at an increase of the overall Strehl ratio; see for instance Kulcsár, Looze, Poyneer, Fedrigo and Hinnen. The common essence of these approaches is the minimization of a quadratic criterion function, yielding so-called 'optimal' or LQG control solutions. Such controllers account for the inherent spatial and temporal correlations in the wavefront phase errors and are in some cases also referred to as 'predictive controllers'.



Generalized plant diagram.

UNDERLYING CONTROL THEORY

Following the H_2-optimal control design approach proposed by Hinnen, the optimization problem is to find a controller C, which:

1. Minimizes the critrion function J that consists of the variance of the wavefront phase error and the weighted control effort:

$$J = \mathrm{E}\left\{\varphi^T(k)\varphi(k) + u^T(k)Qu(k)\right\}$$

where $\varphi(k)$ is a vector of wavefront phases and $u(k)$ a vector of control inputs at time k.

2. Stabilizes the closed-loop system.

To determine the optimal controller C, the design algorithm needs a model of the generalized plant P, that contains the transfer functions from the system inputs (u and w) to the system outputs (φ and s). The controller optimization can be performed using standard optimal control design tools; for instance those in the control toolbox of MATLAB®.

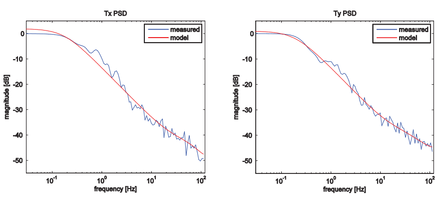
McMath-Pierce solar telescope; NOAO/AURA/NSF.

EXPERIMENTAL SET-UP

Based on the H_2-optimal control design method a real sky experiment has been carried out on the McMath-Pierce solar telescope on Kitt Peak, Arizona. The purpose of the experiment was to validate the favourable results of optimal control, as obtained in simulations and laboratory experiments, with a real-time AO system on a telescope with real sky turbulence.

The AO system at this 1.5 m telescope contains a 37-channel Okotech deformable mirror and a separate tip-tilt mirror on a Piezosystem Jena mount; see (Keller 2003) for more details. The control system driving these mirrors is based on an off-the-shelf Pentium PC with Linux as operating system.

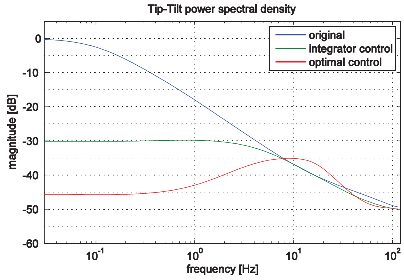
A subspace identification approach is used to acquire the dynamic models for the generalized plant P, in particular a wavefront disturbance model and plant models of both mirror systems. These models are truly data-driven as they are based on sensor data only. The low order disturbance models for the tip and tilt modes show a close match; for instance with respect to the power spectral density functions.



Tip-tilt dynamic models and measured PSD's.

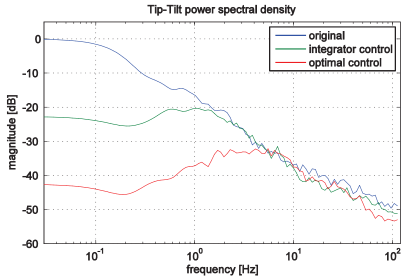
SIMULATION RESULTS

Using the dynamic models for P, the performance of the optimal controller can be simulated and also be compared to the performance of the common integrator controller.

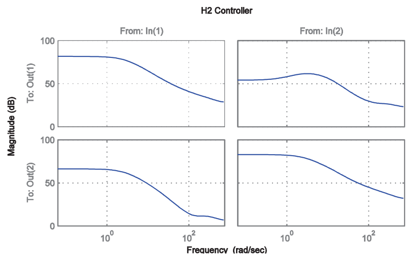


REAL SKY RESULTS

Originally, the validation aimed at controlling the first 20 to 30 modes of the AO system. During the experiments, however, it appeared that the deformable mirror did not have sufficient stroke to cope with the strong wavefront aberrations as measured by the AO wavefront sensor on the particular days of the experiments. Therefore, it was decided to focus on optimal control of the lower aberration modes tip and tilt only. The specific validation test took place on November 14, 2010.



Averaged experimental results at the telescope.



Magnitude of the 2x2 controller frequency response.

CONCLUSIONS

Optimal control for AO tip-tilt modes has been demonstrated on a telescope with real sky turbulence. It obtains a substantially higher disturbance rejection compared to integrator control. The performance agrees well with simulations.

Similar results are expected for higher order modes tests. For continuous operation an adaptive control implementation would be beneficial to deal with time-varying turbulence properties.

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